LA-13316-MS

Frequency Estimates for Aircraft Crashes into Nuclear Facilities at Los Alamos National Laboratory (LANL)

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FREQUENCY ESTIMATES FOR AIRCRAFT CRASHES INTO NUCLEAR FACILITIES AT LOS ALAMOS NATIONAL LABORATORY (LANL)

by

George D. Heindel

ABSTRACT

In October 1996, the Department of Energy (DOE) issued a new standard for evaluating accidental aircraft crashes into hazardous facilities.[1] This document uses the method prescribed in the new standard to evaluate the likelihood of this type of accident occurring at Los Alamos National Laboratory's nuclear facilities.

BACKGROUND

According to DOE order and standard (DOE Order 5480.23[2] and DOE-STD-3009-94[3]), the likelihood of an airplane accidentally crashing into a nuclear facility must be considered in the safety analysis report (SAR) for that facility. If the likelihood is credible (generally defined as greater than 10^{-6} yr^{-1}), the consequences are evaluated and the scenario is included in the spectrum of accidents that make up the facility risk. The method that was used until now for estimating the likelihood of this scenario at Los Alamos is documented in an LA series report by Selvage.[4] For each Los Alamos nuclear facility, this method was used to estimate the likelihood of an airplane crash occurring. In each case it was estimated to be less than the 10^{-6} yr^{-1} limit of credibility, and so the consequences were not evaluated and the risks not considered as part of the facility risk. The method used was never endorsed by DOE. With the publication of DOE-STD-3014-94, there is now a DOE-prescribed method.

METHOD

The DOE-prescribed method for estimating the frequency of aircraft crashes into a given facility is described by the following four-factor formula [Equation (5-1) in DOE-STD-3014-96]:

$$F = \sum_{i,j,k} N_{ijk} * P_{ijk} * f_{ijk}(x,y) * A_{ij} \qquad (1)$$

where

F = estimated annual aircraft crash impact frequency for the facility of interest (no./yr);

N_{ijk} = estimated annual number of site-specific aircraft operations (i.e., takeoffs, landings, and in-flights) for each applicable summation parameter (no./yr);

P_{ijk} = aircraft crash rate (per takeoff or landing for near-airport phases and per flight for the in-flight (nonairport) phase of operation for each applicable summation parameter;

$f_{ijk}(x,y)$ = aircraft crash location conditional probability (per square mile), given a crash, evaluated at the facility location for each applicable summation parameter;

A_{ij} = the site-specific effective area, including skid and fly-in effective areas (square miles), for the facility of interest for each applicable summation parameter, aircraft category or subcategory, and flight phase for military aviation;

i = (index for flight phases): $i = 1$, 2, and 3 (takeoff, in-flight, and landing);

j = (index for aircraft category or subcategory): $j = 1, 2, ..., 11$;

k = (index for flight source): $k = 1, 2, ..., K$ (possible multiple runways and nonairport operations); and

$\sum_{i,j,k} = \sum_{k}\sum_{j}\sum_{i}$ = site-specific summation over flight phase i; aircraft category or subcategory j; and flight source k.

In Los Alamos there is one airport, which has a single runway that is used by both general and commercial aviation (an air taxi service). In-flight operations are considered for general, commercial, and military aviation.

AIRPORT OPERATIONS

Number of Aircraft Operations *N*

The number of airport operations (both takeoffs and landings) at the Los Alamos airport was taken from a Los Alamos report[4] that used data from the airport log for 1993. These data were qualitatively confirmed in 1997. During 1993 there were a total of 3600 commercial flight takeoffs and landings and 8834 general aviation takeoffs and landings.

The value of N for in-flight crashes is collapsed into a combined $NPf(x,y)$ parameter provided by DOE-STD-3014-96. The in-flight (nonairport) method is described below.

Aircraft Crash Rate *P*

Aircraft crash rates by aircraft category, subcategory, and flight phase are provided in Table 1, which was taken from DOE-STD-3014-96, Table B-1. The value of *P* for in-flight crashes is collapsed into a combined $NPf(x,y)$ parameter, also provided by the DOE standard. The in-flight method is described below.

Table 1. Aircraft Crash Rates by Category, Subcategory, and Flight Phase

AIRCRAFT	CRASH RATE	
	Crashes per takeoff	Crashes per landing
General Aviation		
1. Fixed-Wing Single-Engine Reciprocating	1.1E-5	2.0E-5
2. Fixed-Wing Multiengine Reciprocating	9.3E-6	2.3E-5
3. Fixed-Wing Turboprop	3.5E-6	8.3E-6
4. Fixed-Wing Turbojet	1.4E-6	4.7E-6
Representative Fixed-Wing	1.1E-5	2.0E-5
Representative Helicopter	2.5E-5	
Commercial		
1. Air Carrier	1.9E-7	2.8E-7
2. Air Taxi	1.0E-6	2.3E-6
Military		
1. Large Aircraft	5.7E-7	1.6E-6
2. Small Aircraft	1.8E-6	3.3E-6

Aircraft Crash Location Conditional Probability $f_{ijk}(x,y)$

Given that a crash occurs upon takeoff or landing (with frequency *P* from Table 1), the DOE standard provides the spatial distribution of ground impacts in units of mi^{-2} as a function of location with respect to the airport $f_{ijk}(x,y)$ for each type of activity and aircraft (i and j). These numbers are in a matrix format with the matrix cells' sides each being one mile in length. There is a unique matrix for each type of aircraft and activity (takeoff or landing). Location with respect to the airport is designated as the orthonormal distance to the facility from the middle of the runway in standard Cartesian coordinates (x and y). The positive x direction of the coordinate system is defined as being the direction of the activity (takeoff or landing). The positive y direction relative to x, then, is determined by the right-hand rule. The relevant matrices for the work of this report are

- Table 2: Crash Location Probability $f(x,y)$ for Commercial Aircraft Takeoff
- Table 3: Crash Location Probability $f(x,y)$ for Commercial Aircraft Landing
- Table 4: Crash Location Probability $f(x,y)$ for General Aviation Aircraft Takeoff

- Table 5: Crash Location Probability $f(x,y)$ for General Aviation Aircraft Landing

These tables are reproduced from DOE-STD-3014-96, Tables B-2 through B-5. The $f(x,y)$ values for nonairport (in-flight) operations are collapsed into a combined $NPf(x,y)$ parameter that is also provided by the DOE standard. The in-flight method is described below.

Effective Area A_{ij}

The effective area A_{ij} is the ground-surface area surrounding a facility that, if crashed into by an unobstructed aircraft, would result in an impact on the facility (either by direct fly-in or by skid). Equations (2), (3), and (4), which describe the effective area, are taken from the DOE standard [Equations (B-3 through B-5)].

$$A_{eff} = A_f + A_s \tag{2}$$

where

$$A_f = (WS + R) * H \cot\phi + \frac{2 * L * W * WS}{R} + L * W \tag{3}$$

and

$$A_s = (WS + R) * S \tag{4}$$

where

A_f= effective fly-in area;

A_s = effective skid area;

WS = aircraft wingspan (see Table 6);

R = length of the diagonal of the facility = $(L^2 + W^2)^{0.5}$;

H = height of specific facility;

$\cot\phi$ = mean of the cotangent of the aircraft impact angle (provided in Table 7) (for in-flight crashes use the takeoff mean of the cotangent of the impact angle, if available);

L = length of specific facility;

Table 2. Crash Location Probability *f(x,y)* for Commercial Aircraft Takeoff[a]

X⇒ Y⇓	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11	11,12
13,14							1.1E-5	1.1E-5					
12,13						1.0E-5	1.4E-5	1.3E-5	1.0E-5				
11,12						1.4E-5	1.7E-5	1.6E-5	1.2E-5				
10,11					1.1E-5	1.9E-5	2.2E-5	1.9E-5	1.4E-5				
9,10					1.7E-5	2.6E-5	2.8E-5	2.4E-5	1.6E-5				
8,9				1.1E-5	2.6E-5	3.7E-5	3.7E-5	2.9E-5	1.9E-5	1.1E-5			
7,8				2.0E-5	4.0E-5	5.3E-5	5.0E-5	3.7E-5	2.3E-5	1.3E-5			
6,7			1.1E-5	3.7E-5	6.6E-5	7.8E-5	6.8E-5	4.8E-5	2.9E-5	1.6E-5			
5,6			2.6E-5	7.3E-5	1.1E-4	1.2E-4	9.6E-5	6.3E-5	3.6E-5	1.9E-5			
4,5		1.1E-5	6.8E-5	1.6E-4	2.1E-4	1.9E-4	1.4E-4	8.6E-5	4.7E-5	2.4E-5	1.1E-5		
3,4		4.5E-5	2.0E-4	3.7E-4	4.1E-4	3.3E-4	2.2E-4	1.2E-4	6.4E-5	3.1E-5	1.4E-5		
2,3		2.3E-4	7.3E-4	1.0E-3	9.2E-4	6.4E-4	3.7E-4	1.9E-4	9.2E-5	4.2E-5	1.9E-5		
1,2	1.0E-4	1.8E-3	3.9E-3	3.8E-3	2.6E-3	1.5E-3	7.5E-4	3.5E-4	1.5E-4	6.5E-5	2.8E-5	1.2E-5	
0,1	2.6E-2	1.8E-1	1.5E-1	7.1E-2	2.8E-2	1.1E-2	3.9E-3	1.5E-3	5.5E-4	2.1E-4	8.0E-5	3.1E-5	1.2E-5
-1,0	2.6E-2	1.8E-1	1.5E-1	7.1E-2	2.8E-2	1.1E-2	3.9E-3	1.5E-3	5.5E-4	2.1E-4	8.0E-5	3.1E-5	1.2E-5
-2,-1	1.0E-4	1.8E-3	3.9E-3	3.8E-3	2.6E-3	1.5E-3	7.5E-4	3.5E-4	1.5E-4	6.5E-5	2.8E-5	1.2E-5	
-3,-2		2.3E-4	7.3E-4	1.0E-3	9.2E-4	6.4E-4	3.7E-4	1.9E-4	9.2E-5	4.2E-5	1.9E-5		
-4,-3		4.5E-5	2.0E-4	3.7E-4	4.1E-4	3.3E-4	2.2E-4	1.2E-4	6.4E-5	3.1E-5	1.4E-5		
-5,-4		1.1E-5	6.8E-5	1.6E-4	2.1E-4	1.9E-4	1.4E-4	8.6E-5	4.7E-5	2.4E-5	1.1E-5		
-6,-5			2.6E-5	7.3E-5	1.1E-4	1.2E-4	9.6E-5	6.3E-5	3.6E-5	1.9E-5			
-7,-6			1.1E-5	3.7E-5	6.6E-5	7.8E-5	6.8E-5	4.8E-5	2.9E-5	1.6E-5			
-8,-7				2.0E-5	4.0E-5	5.3E-5	5.0E-5	3.7E-5	2.3E-5	1.3E-5			
-9,-8				1.1E-5	2.6E-5	3.7E-5	3.7E-5	2.9E-5	1.9E-5	1.1E-5			
-10,-9					1.7E-5	2.6E-5	2.8E-5	2.4E-5	1.6E-5				
-11,-10					1.1E-5	1.9E-5	2.2E-5	1.9E-5	1.4E-5				
-12,-11						1.4E-5	1.7E-5	1.6E-5	1.2E-5				
-13,-12						1.0E-5	1.4E-5	1.3E-5	1.0E-5				
-14,-13							1.1E-5	1.1E-5					

[a]Reproduced from DOE-STD-3014-96 (Table B-2).

Table 3. Crash Location Probability *f(x,y)* for Commercial Aircraft Landing[a]

X⇒ Y⇓	-16,-15	-15,-14	-14,-13	-13,-12	-12,-11	-11,-10	-10,-9	-9,-8	-8,-7	-7,-6	-6,-5	-5,-4	-4,-3	-3,-2	-2,-1	-1,0	0,1
5,6					1.2E-5	1.2E-5											
4,5			1.0E-5	1.4E-5	1.9E-5	2.1E-5	2.1E-5	1.6E-5									
3,4			1.4E-5	2.2E-5	3.1E-5	4.0E-5	4.6E-5	4.4E-5	3.4E-5	2.0E-5							
2,3		1.2E-5	2.0E-5	3.4E-5	5.4E-5	7.9E-5	1.1E-4	1.3E-4	1.3E-4	1.1E-4	7.1E-5	3.3E-5					
1,2		1.6E-5	3.1E-5	5.6E-5	1.0E-4	1.7E-4	2.8E-4	4.2E-4	5.8E-4	7.1E-4	7.5E-4	6.5E-4	4.3E-4	1.9E-4	5.1E-5		
0,1	1.4E-5	2.9E-5	5.9E-5	1.2E-4	2.5E-4	5.0E-4	1.0E-3	2.1E-3	4.3E-3	8.6E-3	1.7E-2	3.4E-2	6.3E-2	1.1E-1	1.5E-1	9.9E-2	6.9E-3
-1,0	1.4E-5	2.9E-5	5.9E-5	1.2E-4	2.5E-4	5.0E-4	1.0E-3	2.1E-3	4.3E-3	8.6E-3	1.7E-2	3.4E-2	6.3E-2	1.1E-1	1.5E-1	9.9E-2	6.9E-3
-2,-1		1.6E-5	3.1E-5	5.6E-5	1.0E-4	1.7E-4	2.8E-4	4.2E-4	5.8E-4	7.1E-4	7.5E-4	6.5E-4	4.3E-4	1.9E-4	5.1E-5		
-3,-2		1.2E-5	2.0E-5	3.4E-5	5.4E-5	7.9E-5	1.1E-4	1.3E-4	1.3E-4	1.1E-4	7.1E-5	3.3E-5					
-4,-3			1.4E-5	2.2E-5	3.1E-5	4.0E-5	4.6E-5	4.4E-5	3.4E-5	2.0E-5							
-5,-4			1.0E-5	1.4E-5	1.9E-5	2.1E-5	2.1E-5	1.6E-5									
-6,-5					1.2E-5	1.2E-5											

[a]Reproduced from DOE-STD-3014-96 (Table B-3).

Table 4. Crash Location Probability *f(x,y)* for General Aviation Aircraft Takeoff[a]

X⇒ Y⇓	-4,-3	-3,-2	-2,-1	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8
3,4				1.2E-5	1.8E-4	4.2E-4	1.7E-4	1.4E-5				
2,3			1.1E-5	1.6E-4	1.1E-3	2.2E-3	9.1E-4	4.1E-4	1.1E-3	6.7E-4	6.5E-5	
1,2		1.7E-5	6.2E-4	8.4E-3	1.5E-2	1.0E-2	4.0E-3	2.0E-3	3.2E-3	1.9E-3	2.1E-4	
0,1		3.5E-4	7.1E-3	1.5E-1	2.0E-1	7.2E-2	2.2E-2	5.9E-3	4.6E-3	4.6E-3	1.5E-3	1.7E-4
-1,0	1.1E-5	4.9E-4	8.4E-3	1.5E-1	1.9E-1	6.6E-2	2.1E-2	6.2E-3	4.4E-3	4.5E-3	1.5E-3	1.7E-4
-2,-1		6.1E-5	1.1E-3	9.2E-3	1.3E-2	5.9E-3	2.1E-3	5.2E-4	2.8E-4	3.9E-4	1.4E-4	1.0E-5
-3,-2			1.7E-5	1.0E-4	1.7E-4	4.6E-4	1.0E-3	5.2E-4	8.0E-4	1.7E-3	6.1E-4	3.7E-5
-4,-3					2.6E-5	4.4E-4	1.2E-3	5.8E-4	2.0E-4	3.4E-4	1.3E-4	
-5,-4						1.5E-5	4.3E-5	2.0E-5				

[a]Reproduced from DOE-STD-3014-96 (Table B-4).

Table 5. Crash Location Probability $f(x,y)$ for General Aviation Aircraft Landing[a]

X⇒ Y⇓	-16, -15	-15,-14	-14,-13	-13,-12	-12,-11	-11,-10	-10,-9	-9,-8	-8,-7	-7,-6	-6,-5	-5,-4	-4,-3	-3,-2	-2,-1	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8
5,6													1.5E-5	6.3E-5	1.9E-4	3.5E-4	3.5E-4	1.9E-4	6.2E-5	1.5E-5				
4,5												4.3E-5	1.9E-4	4.3E-4	6.1E-4	6.8E-4	6.0E-4	4.9E-4	3.8E-4	2.4E-4	1.7E-4	8.7E-5	2.0E-5	
3,4										3.3E-5	1.1E-4	2.7E-4	5.2E-4	8.3E-4	9.7E-4	7.6E-4	5.0E-4	3.9E-4	3.7E-4	4.8E-4	4.8E-4	2.3E-4	4.4E-5	
2,3			5.6E-5	2.0E-4	3.3E-4	2.9E-4	1.6E-4	7.1E-5	9.9E-5	3.1E-4	5.0E-4	4.5E-4	7.5E-4	1.5E-3	1.7E-3	1.1E-3	6.0E-4	4.0E-4	4.5E-4	7.1E-4	7.1E-4	3.3E-4	6.0E-5	
1,2		7.2E-5	2.8E-4	5.2E-4	6.1E-4	5.6E-4	4.5E-4	4.5E-4	6.5E-4	8.8E-4	8.7E-4	6.6E-4	1.1E-3	3.0E-3	5.8E-3	1.2E-2	1.1E-2	4.4E-3	1.5E-3	7.0E-4	5.3E-4	3.3E-4	8.9E-5	
0,1	1.2E-5	1.0E-4	3.5E-4	5.3E-4	5.0E-4	5.8E-4	7.4E-4	9.5E-4	1.6E-3	2.9E-3	4.0E-3	4.3E-3	7.2E-3	1.8E-2	3.9E-2	1.6E-1	1.6E-1	2.9E-2	1.1E-2	3.9E-3	2.6E-3	1.7E-3	5.6E-4	6.8E-5
-1,0		7.3E-5	3.1E-4	6.0E-4	6.3E-4	6.0E-4	6.5E-4	6.7E-4	1.1E-3	2.2E-3	3.3E-3	3.8E-3	6.8E-3	1.7E-2	3.7E-2	1.6E-1	1.6E-1	2.8E-2	1.0E-2	4.0E-3	3.0E-3	2.1E-3	6.5E-4	7.7E-5
-2,-1			5.8E-5	1.9E-4	3.0E-4	3.9E-4	3.7E-4	2.1E-4	2.5E-4	3.5E-4	5.1E-4	7.4E-4	1.0E-3	2.3E-3	4.9E-3	1.1E-2	1.0E-2	3.8E-3	1.6E-3	8.2E-4	6.0E-4	4.0E-4	1.2E-4	1.4E-5
-3,-2			4.6E-5	1.6E-4	2.1E-4	1.5E-4	1.0E-4	7.8E-5	1.9E-4	3.2E-4	3.9E-4	5.3E-4	6.8E-4	1.1E-3	1.4E-3	1.2E-3	9.4E-4	6.8E-4	4.7E-4	4.2E-4	3.7E-4	1.6E-4	2.7E-5	
-4,-3								5.2E-5	1.6E-4	2.0E-4	2.5E-4	6.0E-4	8.3E-4	5.8E-4	3.6E-4	3.9E-4	3.3E-4	1.4E-4	1.4E-4	2.8E-4	2.4E-4	8.1E-5		
-5,-4								4.8E-5	1.5E-4	1.7E-4	1.8E-4	3.5E-4	4.8E-4	3.8E-4	2.5E-4	3.3E-4	3.1E-4	1.2E-4	1.2E-4	2.6E-4	2.2E-4	6.8E-5		
-6,-5												1.3E-5	1.6E-5	2.5E-5	1.1E-4	3.0E-4	3.0E-4	1.1E-4	3.5E-5	5.3E-5	4.5E-5	1.4E-5		

[a]Reproduced from DOE-STD-3014-96 (Table B-5).

W = width of specific facility; and

S = aircraft skid distance (mean value), provided in Table 8 (for in-flight crashes use the takeoff skid length, if available).

Facility dimensions were taken from the Selvedge report.[4] Wingspans, impact angles, and skid distances, were taken from the DOE standard (Tables B-16, -17, and -18) and reproduced here as Tables 6, 7, and 8.

Table 6. Representative Wingspans (*WS*) for Commercial, General Aviation, and Military Aircraft

General Aviation	Piston Engine	Turboprop	Turbojet	Helicopters
50 ft	50 ft	73 ft	50 ft	50 ft

Commercial Aviation	Air Carrier	Air Taxi
	98 ft	59 ft

Military Aviation	Large Aircraft	Small Aircraft High Performance[a]	Small Aircraft Low Performance[b]
	223 ft	78 ft	110 ft

[a]Includes fighters, attackers, and trainers.
[b]Includes other small aircraft.

Table 7. Values of the Mean of the Cotangent of the Impact Angle ($cot\phi$)

Aircraft Category	Commercial Aviation	General Aviation	Helicopters	Military Aviation			
				Large Aircraft		Small Aircraft	
				Takeoff	Landing	Takeoff	Landing
Mean ($cot\phi$)	10.2	8.2	0.58	7.4	9.7	8.4	10.4

Table 8. Mean Skid Distances (*S*) for Each Aircraft Category

Aircraft Category	Commercial Aviation	General Aviation	Helicopters	Military Aviation			
				Large Aircraft		Small Aircraft	
				Takeoff	Landing	Takeoff	Landing
Mean Skid Distance (ft)	1440	60	0	780	368	246	447

NONAIRPORT OPERATIONS

Aircraft crashes can occur as a result of in-flight problems not associated with takeoffs and landings at an airport. For our previous analytical method[4] we determined an estimated impact

frequency as a function of the distance of the facility from an established airway. Aircraft are no longer restricted to established airways but fly point-to-point. For this reason, the DOE standard suggests a different approach. By dividing the continental United States (CONUS) into regions; considering the amount of air traffic in that region; applying a base in-flight crash rate; and operating under the assumption that a crash is equally likely to occur at any area within that region, the Standard collapsed the first three terms in Equation (1) into a single term that is specific to each DOE site (e.g., Los Alamos). These values, which depend on both the location of the sites and the category of the aircraft, are presented in Tables 9 and 10. The values are then multiplied by the effective areas (in sq mi) of the facilities, providing the impact frequency from this operational phase.

Table 9. DOE Site-Specific Values and Maximum, Minimum, and Average Values for the Continental United States (CONUS) of *NPf(x,y)* for General Aviation (GA) Nonairport Operations[a,b]

Site	Value of *NPf(x,y)*
CONUS, Maximum	3E-3
CONUS, Minimum	1E-7
CONUS, Average	2E-4
Argonne National Laboratory	3E-3
Brookhaven National Laboratory	5E-4
Hanford	1E-4
Idaho National Engineering Laboratory	9E-5
Kansas City Plant	6E-4
Los Alamos National Laboratory	2E-4
Lawrence Livermore National Laboratory	1E-4
Mound	4E-4
Nevada Test Site	8E-5
Oak Ridge National Laboratory	2E-3
Pantex	7E-5
Pinellas	3E-4
Rocky Flats	2E-3
Sandia National Labortories	1E-3
Savannah River Site	2E-4

[a]These values are given in crashes per square mile, per year, that are centered at the site.

[b]Reproduced from DOE-STD-3014-96 (Table B-14).

Table 10. DOE Site-Specific Values and Maximum, Minimum, and Average CONUS Values of *NPf(x,y)* for Commercial and Military Aviation Nonairport Operations[a,b]

Site	Values of NPf(x,y)			
	Air Carrier	Air Taxi	Large Military	Small Military
CONUS, Maximum	2E-6	8E-6	7E-7	6E-6
CONUS, Minimum	7E-8	4E-7	6E-8	4E-8
CONUS, Average	4E-7	1E-6	2E-7	4E-6
Argonne National Laboratory	7E-7	4E-6	9E-8	8E-7
Brookhaven National Laboratory	2E-6	8E-6	7E-7	2E-7
Hanford	1E-7	1E-6	1E-7	4E-8
Idaho National Engineering Laboratory	7E-8	4E-7	9E-8	7E-7
Kansas City Plant	4E-7[c]	1E-6[c]	2E-7	1E-6
Los Alamos National Laboratory	2E-7	3E-6	1E-7	5E-6
Lawrence Livermore National Laboratory	5E-7	2E-6	2E-7	3E-6
Mound	6E-7	3E-6	1E-7	2E-6
Nevada Test Site	5E-7	2E-6	2E-7	6E-6
Oak Ridge National Laboratory	6E-7	2E-6	1E-7	6E-7
Pantex	2E-7	3E-7	1E-7	5E-6
Pinellas	4E-7	1E-6	2E-7	4E-6
Rocky Flats	2E-7	6E-7	9E-8	9E-7
Sandia National Laboratories	2E-7	3E-7	1E-7	5E-6
Savannah River Site	6E-7	2E-6	1E-7	6E-7

[a]These values are given in crashes per square mile, per year, that are centered at the site.

[b]Reproduced from DOE-STD-3014-96 (Table B-15).

[c]The average CONUS was used for these entries.

RESULTS

Table 11 lists the total impact frequency estimates for each of the traditional nuclear facilities at Los Alamos, including airport and nonairport operations, takeoffs, landings, general aviation, commercial aviation, and military aviation.

Table 11. Total Impact Frequency Estimates for Each of the Traditional Nuclear Facilities at Los Alamos

Facility Name	Location	Total Impact Frequency per DOE-STD-3014-96 (yr–1)
CMR	TA-3-29	1.2E-05
WETF	TA-16-205	1.0E-06
Hillside Vault	TA-18-26	1.1E-07
LACEF Kiva 1	TA-18-23	5.0E-07
LACEF Kiva 2	TA-18-32	5.3E-07
LACEF Kiva 3	TA-18-116	6.3E-07
TSTA	TA-21-155	1.2E-04
TSFF	TA-21-209	9.6E-05
RLWTF	TA-50-1	8.3E-06
TDF	TA-50-37	3.0E-06
WCRRF	TA-50-69	1.6E-06
Area G	TA-54-G	3.8E-06
Plutonium Facility	TA-55-4	5.6E-06

The tables in Appendixes A-M (one for each facility) provide the details of the calculations that resulted in the values shown in Table 11.

CONCLUSIONS

All LANL traditional nuclear facilities, except those at TA-18, have estimated aircraft crash impact frequencies that are greater than or equal to 10^{-6} per year according to the DOE-STD-3014-96 recommended method for calculating that frequency. The estimated frequency for WETF is very close to this limit, but those for others are significantly greater. The estimated frequency for WETF will increase approximately linearly with the planned increase in facility size.

Generally these results are dominated by the estimates for general aviation activity at the airport, and within that category, by crashes during landings.

As one might expect, the highest estimates are for the two facilities located at TA-21: TSTA and TSFF. These have total impact frequency estimates of 1.2E-04 and 9.6E-05 yr^{-1} respectively. While both commercial and general aviation contributions are greater than 10^{-6} yr^{-1}, the latter dominates the results.

These results suggest that future SARs and updates of old SARs should include consideration of this accident scenario. Consequence analyses are the logical next step for these facilities, and a standard approach for performing these analyses is also contained in DOE-STD-3014-96.

REFERENCES

1. Accident Analysis for Aircraft Crash into Hazardous Facilities, DOE-STD-3014-96, U.S. Department of Energy, Washington, DC, October 1996.

2. Nuclear Safety Analysis Reports, DOE Order 5480.23, U.S. Department of Energy, Washington, DC, April 10, 1992.

3. Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports, DOE-STD-3009-94, U.S. Department of Energy, Washington, DC, July 1994.

4. Selvage, Ronald D., Evaluation of Aircraft Crash Hazard at Los Alamos National Laboratory Facilities, Los Alamos National Laboratory report LA-13105, July 1996.

Appendix A

CMR (TA-3-29) Aircraft Crash Frequency Estimates

Table A-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
x,y	Orthonormal distance from runway		
	takeoff		-2.66,-1.14
	landing		+2.66,+1.14
L	Building length	6.60E+02	1.25E-01
W	Building width	6.60E+02	1.25E-01
H	Building height	5.00E+01	9.47E-03
R	Building diagonal	9.33E+02	1.77E-01
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
f(x,y)	Crash location probability		
	takeoff (Table 2)		0.0E+00
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
Cot(ϕ)	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	9.97E+05	3.58E-02
A_s	Effective skid area [Eq. (5)]	1.43E+06	5.13E-02
A_{eff}	Effective target area [Eq. (3)]	2.43E+06	8.70E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		0.0E+00
	landings		0.0E+00
	total		0.0E+00

Table A-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		6.1E-05
	landing (Table 5)		1.5E-03
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	8.85E+05	3.18E-02
A_s	Effective skid area [Eq. (5)]	5.90E+04	2.12E-03
A_{eff}	Effective target area [Eq. (3)]	9.44E+05	3.39E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		1.0E-07
	landings		4.5E-06
	total		4.6E-06
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		4.6E-06

Appendix B

WETF (TA-16-205) Aircraft Crash Frequency Estimates

Table B-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
x,y	Orthonormal distance from runway		
	takeoff		-3.9, -3.6
	landing		+3.9, +3.6
L	Building length	1.05E+02	1.99E-02
W	Building width	7.00E+01	1.33E-02
H	Building height	6.00E+01	1.14E-02
R	Building diagonal	1.26E+02	2.39E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
f(x,y)	Crash location probability		
	takeoff (Table 2)		0.0E+00
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
Cot(ϕ)	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	1.28E+05	4.58E-03
A_s	Effective skid area [Eq. (5)]	2.67E+05	9.57E-03
A_{eff}	Effective target area [Eq. (3)]	3.94E+05	1.41E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		0.0E+00
	landings		0.0E+00
	total		0.0E+00

Table A-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	1.07E+06	3.84E-02
	small aircraft	9.76E+05	3.50E-02
A_s	Effective skid area [Eq. (5)]		
	large aircraft	9.02E+05	3.24E-02
	small aircraft	2.57E+05	9.21E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	1.97E+06	7.08E-02
	small aircraft	1.23E+06	4.42E-02
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		2.6E-07
	general aviation		6.8E-06
	military (large)		7.1E-09
	military (small)		2.2E-07
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		7.3E-06
Total Impact Frequency (per yr)			
	airport + nonairport operations		1.2E-05

Table B-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		0.0E+00
	landing (Table 5)		4.8E-04
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	9.99E+04	3.58E-03
A_s	Effective skid area [Eq. (5)]	1.06E+04	3.79E-04
A_{eff}	Effective target area [Eq. (3)]	1.10E+05	3.96E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		0.0E+00
	landings		1.7E-07
	total		1.7E-07
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		1.7E-07

Table B-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
$NPf(x,y)$	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	1.88E+05	6.76E-03
	small aircraft	1.39E+05	4.99E-03
A_s	Effective skid area [Eq. (5)]		
	large aircraft	2.72E+05	9.77E-03
	small aircraft	5.81E+04	2.08E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	4.61E+05	1.65E-02
	small aircraft	1.97E+05	7.08E-03
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		4.2E-08
	general aviation		7.9E-07
	military (large)		1.7E-09
	military (small)		3.5E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		8.7E-07
Total Impact Frequency (per yr)			
	airport + nonairport operations		1.0E-06

Appendix C

Hillside Vault (TA-18-26) Aircraft Crash Frequency Estimates

Table C-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		+0.79, -2.5
	landing		-0.79, +2.5
L	Building length	2.50E+01	4.73E-03
W	Building width	2.50E+01	4.73E-03
H	Building height	0.00E+00	0.00E+00
R	Building diagonal	3.54E+01	6.70E-03
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
$f(x,y)$	Crash location probability		
	takeoff (Table 2)		2.3E-04
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	2.71E+03	9.72E-05
A_s	Effective skid area [Eq. (5)]	1.36E+05	4.87E-03
A_{eff}	Effective target area [Eq. (3)]	1.39E+05	4.97E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		2.1E-09
	landings		0.0E+00
	total		2.1E-09

Table C-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		1.7E-04
	landing (Table 5)		1.1E-03
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	2.39E+03	8.58E-05
A_s	Effective skid area [Eq. (5)]	5.12E+03	1.84E-04
A_{eff}	Effective target area [Eq. (3)]	7.51E+03	2.70E-04
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		2.2E-09
	landings		2.6E-08
	total		2.8E-08
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		3.0E-08

Table C-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	8.51E+03	3.05E-04
	small aircraft	4.51E+03	1.62E-04
A_s	Effective skid area [Eq. (5)]		
	large aircraft	2.02E+05	7.23E-03
	small aircraft	3.58E+04	1.28E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	2.10E+05	7.53E-03
	small aircraft	4.03E+04	1.44E-03
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		1.5E-08
	general aviation		5.4E-08
	military (large)		7.5E-10
	military (small)		7.2E-09
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		7.7E-08
Total Impact Frequency (per yr)			
	airport + nonairport operations		1.1E-07

Appendix D

LACEF Kiva 1 (TA-18-23) Aircraft Crash Frequency Estimates

Table D-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		+0.59, -2.39
	landing		-0.59, +2.39
L	Building length	6.10E+01	1.16E-02
W	Building width	4.75E+01	9.00E-03
H	Building height	2.61E+01	4.94E-03
R	Building diagonal	7.73E+01	1.46E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
$f(x,y)$	Crash location probability		
	takeoff (Table 2)		2.3E-04
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	4.36E+04	1.56E-03
A_s	Effective skid area [Eq. (5)]	1.96E+05	7.04E-03
A_{eff}	Effective target area [Eq. (3)]	2.40E+05	8.61E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		3.6E-09
	landings		0.0E+00
	total		3.6E-09

Table D-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		1.7E-04
	landing (Table 5)		1.1E-03
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	3.39E+04	1.22E-03
A_s	Effective skid area [Eq. (5)]	7.64E+03	2.74E-04
A_{eff}	Effective target area [Eq. (3)]	4.15E+04	1.49E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		1.2E-08
	landings		1.4E-07
	total		1.6E-07
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		1.6E-07

Table D-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	7.76E+04	2.78E-03
	small aircraft	5.22E+04	1.87E-03
A_s	Effective skid area [Eq. (5)]		
	large aircraft	2.34E+05	8.40E-03
	small aircraft	4.61E+04	1.65E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	3.12E+05	1.12E-02
	small aircraft	9.83E+04	3.53E-03
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		2.6E-08
	general aviation		3.0E-07
	military (large)		1.1E-09
	military (small)		1.8E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		3.4E-07
Total Impact Frequency (per yr)			
	airport + nonairport operations		5.0E-07

Appendix E

LACEF Kiva 2 (TA-18-32) Aircraft Crash Frequency Estimates

Table E-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		+0.54, -2.64
	landing		-0.54, +2.64
L	Building length	5.85E+01	1.11E-02
W	Building width	5.75E+01	1.09E-02
H	Building height	2.61E+01	4.94E-03
R	Building diagonal	8.20E+01	1.55E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
$f(x,y)$	Crash location probability		
	takeoff (Table 2)		2.3E-04
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	4.57E+04	1.64E-03
A_s	Effective skid area [Eq. (5)]	2.03E+05	7.28E-03
A_{eff}	Effective target area [Eq. (3)]	2.49E+05	8.93E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		3.7E-09
	landings		0.0E+00
	total		3.7E-09

Talbe E-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
f(x,y)	Crash location probability		
	takeoff (Table 4)		1.7E-04
	landing (Table 5)		1.1E-03
WS	Wingspan (Table 6)	50	
Cot(phi)	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	3.57E+04	1.28E-03
A_s	Effective skid area [Eq. (5)]	7.92E+03	2.84E-04
A_{eff}	Effective target area [Eq. (3)]	4.36E+04	1.57E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		1.3E-08
	landings		1.5E-07
	total		1.6E-07
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		1.7E-07

Table E-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	8.06E+04	2.89E-03
	small aircraft	5.45E+04	1.95E-03
A_s	Effective skid area [Eq. (5)]		
	large aircraft	2.38E+05	8.53E-03
	small aircraft	4.72E+04	1.69E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	3.18E+05	1.14E-02
	small aircraft	1.02E+05	3.65E-03
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		2.7E-08
	general aviation		3.1E-07
	military (large)		1.1E-09
	military (small)		1.8E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		3.6E-07
Total Impact Frequency (per yr)			
	airport + nonairport operations		5.3E-07

Appendix F

LACEF Kiva 3 (TA-18-116) Aircraft Crash Frequency Estimates

Table F-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		+0.85, -2.62
	landing		-0.85, +2.62
L	Building length	8.10E+01	1.53E-02
W	Building width	6.40E+01	1.21E-02
H	Building height	2.61E+01	4.94E-03
R	Building diagonal	1.03E+02	1.96E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
$f(x,y)$	Crash location probability		
	takeoff (Table 2)		2.3E-04
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	5.43E+04	1.95E-03
A_s	Effective skid area [Eq. (5)]	2.34E+05	8.38E-03
A_{eff}	Effective target area [Eq. (3)]	2.88E+05	1.03E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		4.3E-09
	landings		0.0E+00
	total		4.3E-09

Table F-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		1.7E-04
	landing (Table 5)		1.1E-03
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	4.30E+04	1.54E-03
A_s	Effective skid area [Eq. (5)]	9.19E+03	3.30E-04
A_{eff}	Effective target area [Eq. (3)]	5.22E+04	1.87E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		1.5E-08
	landings		1.8E-07
	total		2.0E-07
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		2.0E-07

Table F-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(phi)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	9.06E+04	3.25E-03
	small aircraft	6.30E+04	2.26E-03
A_s	Effective skid area [Eq. (5)]		
	large aircraft	2.54E+05	9.13E-03
	small aircraft	5.25E+04	1.88E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	3.45E+05	1.24E-02
	small aircraft	1.15E+05	4.14E-03
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		3.1E-08
	general aviation		3.7E-07
	military (large)		1.2E-09
	military (small)		2.1E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		4.3E-07
Total Impact Frequency (per yr)			
	airport + nonairport operations		6.3E-07

Appendix G

TSTA (TA-21-155) Aircraft Crash Frequency Estimates

Table G-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		-0.096, -0.26
	landing		+0.096, +0.26
L	Building length	9.00E+01	1.70E-02
W	Building width	7.70E+01	1.46E-02
H	Building height	9.80E+01	1.86E-02
R	Building diagonal	1.18E+02	2.24E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
$f(x,y)$	Crash location probability		
	takeoff (Table 2)		2.6E-02
	landing (Table 3)		6.9E-03
WS	Wingspan (Table 6)	59	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	1.91E+05	6.86E-03
A_s	Effective skid area [Eq. (5)]	2.56E+05	9.17E-03
A_{eff}	Effective target area [Eq. (3)]	4.47E+05	1.60E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		7.5E-07
	landings		4.6E-07
	total		1.2E-06

Table G-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		1.5E-01
	landing (Table 5)		1.6E-01
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	1.48E+05	5.31E-03
A_s	Effective skid area [Eq. (5)]	1.01E+04	3.63E-04
A_{eff}	Effective target area [Eq. (3)]	1.58E+05	5.68E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		4.1E-05
	landings		8.0E-05
	total		1.2E-04
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		1.2E-04

Table G-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
$NPf(x,y)$	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	2.81E+05	1.01E-02
	small aircraft	2.08E+05	7.46E-03
A_s	Effective skid area [Eq. (5)]		
	large aircraft	2.66E+05	9.55E-03
	small aircraft	5.62E+04	2.02E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	5.47E+05	1.96E-02
	small aircraft	2.64E+05	9.47E-03
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		4.8E-08
	general aviation		1.1E-06
	military (large)		2.0E-09
	military (small)		4.7E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		1.2E-06
Total Impact Frequency (per yr)			
	airport + nonairport operations		1.2E-04

Appendix H

TSFF (TA-21-209) Aircraft Crash Frequency Estimates

Table H-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		-0.053, -0.28
	landing		+0.053, +0.28
L	Building length	9.63E+01	1.82E-02
W	Building width	6.23E+01	1.18E-02
H	Building height	7.50E+01	1.42E-02
R	Building diagonal	1.15E+02	2.17E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
$f(x,y)$	Crash location probability		
	takeoff (Table 2)		2.6E-02
	landing (Table 3)		6.9E-03
WS	Wingspan (Table 6)	59	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	1.45E+05	5.20E-03
A_s	Effective skid area [Eq. (5)]	2.50E+05	8.97E-03
A_{eff}	Effective target area [Eq. (3)]	3.95E+05	1.42E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		6.6E-07
	landings		4.0E-07
	total		1.1E-06

Table H-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		1.5E-01
	landing (Table 5)		1.6E-01
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	1.13E+05	4.04E-03
A_s	Effective skid area [Eq. (5)]	9.88E+03	3.54E-04
A_{eff}	Effective target area [Eq. (3)]	1.22E+05	4.39E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		3.2E-05
	landings		6.2E-05
	total		9.4E-05
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		9.5E-05

Table H-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	2.17E+05	7.77E-03
	small aircraft	1.59E+05	5.71E-03
A_s	Effective skid area [Eq. (5)]		
	large aircraft	2.63E+05	9.45E-03
	small aircraft	5.53E+04	1.98E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	4.80E+05	1.72E-02
	small aircraft	2.14E+05	7.69E-03
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		4.3E-08
	general aviation		8.8E-07
	military (large)		1.7E-09
	military (small)		3.8E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		9.6E-07
Total Impact Frequency (per yr)			
	airport + nonairport operations		9.6E-05

Appendix I

RLWTF (TA-50-1) Aircraft Crash Frequency Estimates

Table I-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		-1.24, -1.45
	landing		+1.24, +1.45
L	Building length	3.10E+02	5.87E-02
W	Building width	2.33E+02	4.41E-02
H	Building height	6.50E+01	1.23E-02
R	Building diagonal	3.88E+02	7.34E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
$f(x,y)$	Crash location probability		
	takeoff (Table 2)		0.0E+00
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	3.90E+05	1.40E-02
A_s	Effective skid area [Eq. (5)]	6.43E+05	2.31E-02
A_{eff}	Effective target area [Eq. (3)]	1.03E+06	3.71E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		0.0E+00
	landings		0.0E+00
	total		0.0E+00

Table I-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		1.1E-03
	landing (Table 5)		4.4E-03
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	3.24E+05	1.16E-02
A_s	Effective skid area [Eq. (5)]	2.63E+04	9.42E-04
A_{eff}	Effective target area [Eq. (3)]	3.50E+05	1.26E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		6.7E-07
	landings		4.9E-06
	total		5.6E-06
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		5.6E-06

Table I-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	4.49E+05	1.61E-02
	small aircraft	3.85E+05	1.38E-02
A_s	Effective skid area [Eq. (5)]		
	large aircraft	4.76E+05	1.71E-02
	small aircraft	1.22E+05	4.39E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	9.26E+05	3.32E-02
	small aircraft	5.07E+05	1.82E-02
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		1.1E-07
	general aviation		2.5E-06
	military (large)		3.3E-09
	military (small)		9.1E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		2.7E-06
Total Impact Frequency (per yr)			
	airport + nonairport operations		8.3E-06

Appendix J

TDF (TA-50-37) Aircraft Crash Frequency Estimates

Table J-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		-1.33, -1.46
	landing		+1.33, +1.46
L	Building length	1.42E+02	2.69E-02
W	Building width	1.30E+02	2.46E-02
H	Building height	4.25E+01	8.05E-03
R	Building diagonal	1.93E+02	3.65E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
$f(x,y)$	Crash location probability		
	takeoff (Table 2)		0.0E+00
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	1.39E+05	4.98E-03
A_s	Effective skid area [Eq. (5)]	3.62E+05	1.30E-02
A_{eff}	Effective target area [Eq. (3)]	5.01E+05	1.80E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		0.0E+00
	landings		0.0E+00
	total		0.0E+00

Table J-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		1.1E-03
	landing (Table 5)		4.4E-03
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	1.13E+05	4.04E-03
A_s	Effective skid area [Eq. (5)]	1.46E+04	5.22E-04
A_{eff}	Effective target area [Eq. (3)]	1.27E+05	4.56E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		2.4E-07
	landings		1.8E-06
	total		2.0E-06
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		2.0E-06

Table J-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	1.92E+05	6.88E-03
	small aircraft	1.48E+05	5.29E-03
A_s	Effective skid area [Eq. (5)]		
	large aircraft	3.24E+05	1.16E-02
	small aircraft	7.44E+04	2.67E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	5.16E+05	1.85E-02
	small aircraft	2.22E+05	7.96E-03
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		5.4E-08
	general aviation		9.1E-07
	military (large)		1.9E-09
	military (small)		4.0E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		1.0E-06
Total Impact Frequency (per yr)			
	airport + nonairport operations		3.0E-06

Appendix K

WCRRF (TA-50-69) Aircraft Crash Frequency Estimates

Table K-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		-1.37, -1.50
	landing		+1.37, +1.50
L	Building length	9.00E+01	1.70E-02
W	Building width	4.50E+01	8.52E-03
H	Building height	4.10E+01	7.77E-03
R	Building diagonal	1.01E+02	1.91E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
f(x,y)	Crash location probability		
	takeoff (Table 2)		0.0E+00
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
Cot(ϕ)	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	7.56E+04	2.71E-03
A_s	Effective skid area [Eq. (5)]	2.30E+05	8.24E-03
A_{eff}	Effective target area [Eq. (3)]	3.05E+05	1.10E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		0.0E+00
	landings		0.0E+00
	total		0.0E+00

Table K-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		1.1E-03
	landing (Table 5)		4.4E-03
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	5.87E+04	2.11E-03
A_s	Effective skid area [Eq. (5)]	9.04E+03	3.24E-04
A_{eff}	Effective target area [Eq. (3)]	6.78E+04	2.43E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		1.3E-07
	landings		9.4E-07
	total		1.1E-06
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		1.1E-06

Table K-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	1.20E+05	4.31E-03
	small aircraft	8.54E+04	3.06E-03
A_s	Effective skid area [Eq. (5)]		
	large aircraft	2.52E+05	9.05E-03
	small aircraft	5.18E+04	1.86E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	3.73E+05	1.34E-02
	small aircraft	1.37E+05	4.92E-03
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		3.3E-08
	general aviation		4.9E-07
	military (large)		1.3E-09
	military (small)		2.5E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		5.4E-07
Total Impact Frequency (per yr)			
	airport + nonairport operations		1.6E-06

Appendix L

Area G (TA-54-G) Aircraft Crash Frequency Estimates

Table L-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		+1.63, -2.06
	landing		-1.63, +2.06
L	Building length	3.20E+02	6.06E-02
W	Building width	2.46E+02	4.66E-02
H	Building height	3.80E+01	7.20E-03
R	Building diagonal	4.04E+02	7.64E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
$f(x,y)$	Crash location probability		
	takeoff (Table 2)		7.3E-04
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	2.81E+05	1.01E-02
A_s	Effective skid area [Eq. (5)]	6.66E+05	2.39E-02
A_{eff}	Effective target area [Eq. (3)]	9.47E+05	3.40E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		4.5E-08
	landings		0.0E+00
	total		4.5E-08

Table L-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		4.6E-04
	landing (Table 5)		1.7E-03
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	2.40E+05	8.59E-03
A_s	Effective skid area [Eq. (5)]	2.72E+04	9.76E-04
A_{eff}	Effective target area [Eq. (3)]	2.67E+05	9.57E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		2.1E-07
	landings		1.4E-06
	total		1.7E-06
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		1.7E-06

Table L-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	3.42E+05	1.23E-02
	small aircraft	2.86E+05	1.02E-02
A_s	Effective skid area [Eq. (5)]		
	large aircraft	4.89E+05	1.75E-02
	small aircraft	1.26E+05	4.53E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	8.31E+05	2.98E-02
	small aircraft	4.12E+05	1.48E-02
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		1.0E-07
	general aviation		1.9E-06
	military (large)		3.0E-09
	military (small)		7.4E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		2.1E-06
Total Impact Frequency (per yr)			
	airport + nonairport operations		3.8E-06

Appendix M

Plutonium Facility (TA-55-4) Aircraft Crash Frequency Estimates

Table M-1. Airport Operations (Takeoffs and Landings)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
Facility Parameters			
(x,y)	Orthonormal distance from runway		
	takeoff		-1.49, -1.42
	landing		+1.49, +1.42
L	Building length	2.84E+02	5.38E-02
W	Building width	2.62E+02	4.96E-02
H	Building height	3.20E+01	6.06E-03
R	Building diagonal	3.86E+02	7.32E-02
Commercial Aircraft (Air Taxi) Calculations			
N	Number of flights per year (takeoffs + landings)		3.6E+03
P	Crash rate (Table 1)		
	per takeoff		1.0E-06
	per landing		2.3E-06
f(x,y)	Crash location probability		
	takeoff (Table 2)		0.0E+00
	landing (Table 3)		0.0E+00
WS	Wingspan (Table 6)	59	
Cot(ϕ)	Cotangent of the crash angle (Table 7)	10.2	
S	Skid distance (Table 8)	1440	
A_f	Effective fly-in area [Eq. (4)]	2.43E+05	8.70E-03
A_s	Effective skid area [Eq. (5)]	6.41E+05	2.30E-02
A_{eff}	Effective target area [Eq. (3)]	8.84E+05	3.17E-02
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		0.0E+00
	landings		0.0E+00
	total		0.0E+00

Table M-1. (cont.)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
General Aviation Aircraft Calculations			
N	Number of flights per year (takeoffs + landings)		8.83E+03
P	Crash rate (Table 1)		
	per takeoff		1.1E-05
	per landing		2.0E-05
$f(x,y)$	Crash location probability		
	takeoff (Table 4)		1.1E-03
	landing (Table 5)		4.4E-03
WS	Wingspan (Table 6)	50	
$Cot(\phi)$	Cotangent of the crash angle (Table 7)	8.2	
S	Skid distance (Table 8)	60	
A_f	Effective fly-in area [Eq. (4)]	2.08E+05	7.47E-03
A_s	Effective skid area [Eq. (5)]	2.62E+04	9.39E-04
A_{eff}	Effective target area [Eq. (3)]	2.34E+05	8.41E-03
F	Impact frequency (per yr) [Eq. (1)]		
	takeoffs		4.5E-07
	landings		3.3E-06
	total		3.7E-06
Total Impact Frequency from Airport Operations (per yr)			
	commercial + general aviation		3.7E-06

Table M-2. Nonairport Operations (Overflights)

Symbol	Parameter	Value (ft, sq ft or dimensionless)	Value (mi, sq mi or dimensionless)
NPf(x,y)	Site-specific crash density rates (Tables 9 and 10) (crashes per sq mi per yr)		
	commercial aviation (air taxi)		3E-06
	general aviation aircraft		2E-04
	large military		1E-07
	small military		5E-06
Effective Area Calculation for Military Aircraft			
WS	Wingspan (Table 6)		
	large aircraft	2.23E+02	
	small aircraft	1.10E+02	
Cot(ϕ)	Cotangent of the crash angle (Table 7)		
	large aircraft	7.4	
	small aircraft	8.4	
S	Skid distance (Table 8)		
	large aircraft	7.80E+02	
	small aircraft	2.46E+02	
A_f	Effective fly-in area [Eq. (4)]		
	large aircraft	3.05E+05	1.09E-02
	small aircraft	2.50E+05	8.97E-03
A_s	Effective skid area [Eq. (5)]		
	large aircraft	4.75E+05	1.71E-02
	small aircraft	1.22E+05	4.38E-03
A_{eff}	Effective target area [Eq. (3)]		
	large aircraft	7.80E+05	2.80E-02
	small aircraft	3.72E+05	1.34E-02
F	Impact frequency (per yr) [Eq. (1)]		
	commercial aviation		9.5E-08
	general aviation		1.7E-06
	military (large)		2.8E-09
	military (small)		6.7E-08
Total Impact Frequency from Nonairport Operations (per yr)			
	commercial + general aviation + military		1.8E-06
Total Impact Frequency (per yr)			
	airport + nonairport operations		5.6E-06

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